Early Journal Content on JSTOR, Free to Anyone in the World

This article is one of nearly 500,000 scholarly works digitized and made freely available to everyone in the world by JSTOR.

Known as the Early Journal Content, this set of works include research articles, news, letters, and other writings published in more than 200 of the oldest leading academic journals. The works date from the mid-seventeenth to the early twentieth centuries.

We encourage people to read and share the Early Journal Content openly and to tell others that this resource exists. People may post this content online or redistribute in any way for non-commercial purposes.

Read more about Early Journal Content at http://about.jstor.org/participate-jstor/individuals/early-journal-content.

JSTOR is a digital library of academic journals, books, and primary source objects. JSTOR helps people discover, use, and build upon a wide range of content through a powerful research and teaching platform, and preserves this content for future generations. JSTOR is part of ITHAKA, a not-for-profit organization that also includes Ithaka S+R and Portico. For more information about JSTOR, please contact support@jstor.org.

IX.

ON SOME PHYSICAL OBSERVATIONS OF THE PLANET SATURN.

By L. Trouvelot.

Read by William A. Rogers, Dec. 14, 1875.

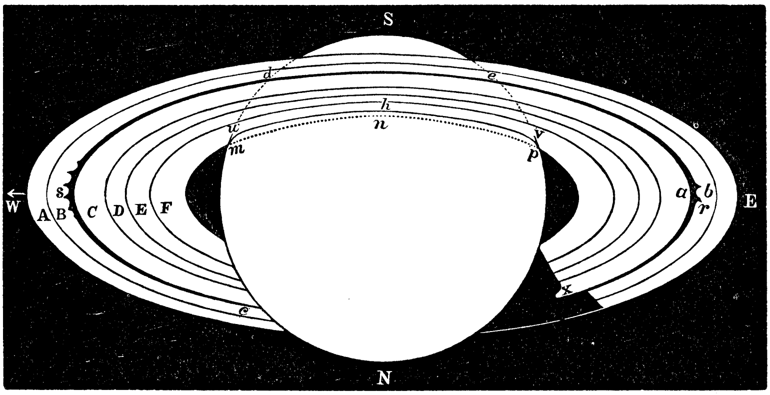
During the last four years I have had many occasions to observe the planet Saturn, and to study its physical constitution under very favorable circumstances. My series of observations extends over more than a hundred nights, many of which were as good as could possibly be desired, both for the steadiness of the image, and for the amount of light.

The observations on which this communication is based were made: 1°. With the fifteen-inch refractor of the Harvard College Observatory, while I was employed by Professor Winlock in making the sketches for the series of the astronomical engravings published by him. By his kind permission I have availed myself of considerable of the data thus obtained. 2°. With the twenty-six-inch refractor of the Washington Observatory while it was still in the hands of Messrs. Alvan Clark & Sons. 3°. With the six-and-one-quarter-inch refractor of my own Physical Observatory at Cambridge. During the past summer, I was honored with an invitation from Admiral C. H. Davis, Superintendent of the Naval Observatory, to visit Washington and make some sketches with the magnificent instrument of this establishment. I thus had an excellent opportunity to confirm all my previous observations. The powers used ranged, according to the amount of light and the steadiness of the atmosphere, from 140 to 700. On good nights, however, higher powers have been tried, but never with advantage, as the light lost by the use of high powers is generally of more importance for good vision than a superior enlargement with a reduced amount of light.

Numerous observers, among whom are such eminent astronomers as Sir William and Sir John Herschel, Otto Struve, Daws, Bond, &c., have made careful studies of this planet; and it is not, therefore, to be expected that very important discoveries remain to be made by later observers. As I have had the opportunity of observing with the same instrument many of the celestial objects previously studied with so much success by Professor George P. Bond, it gives me the greatest pleasure to express my admiration for the accuracy and fidelity of his observations.

The following diagram, representing the outlines of Saturn and its rings, will facilitate my explanations, and give clearness to the subject: —

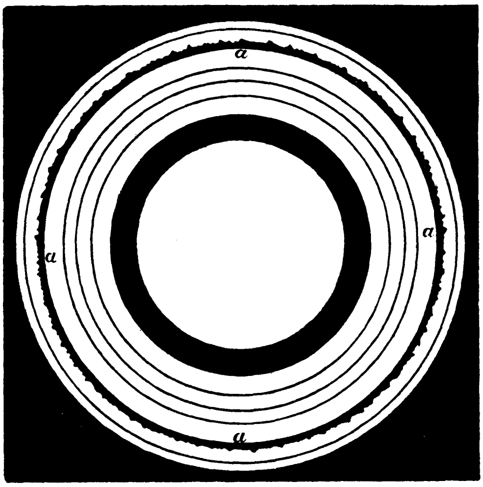
FIG. 1.



By looking at the rings, attention is at once attracted to a conspicuous dark line, apparently concentric with the outer margin of the rings, and boldly surrounding the planet, and adorning it by its sharp contrast. This dark line is known as "the principal division of the rings," and is shown at *a*, Fig. 1. Owing to the effect of perspective, it always appears widest at the two extremities of its major axis, on that portion called "the ansæ," as there only, it is seen without foreshortening. I have carefully compared the intensity of this dark line with the sky outside of the rings, and inside of the ansæ; and I have always found it to be slightly lighter. All my observations also agree in showing this line as appearing a little narrower on the side farther from the observer, at *c*, Fig. 1, than it appears on the opposite side, at *d*. This phenomenon could readily be explained by supposing that the outside margin of the ring *C* is on a plane higher than the ring *B*, and may, consequently, conceal a narrow portion of the dark line. The assumption of such an hypothesis seems to be fully supported by the observations, as will be shown hereafter. It is furthermore to be remarked, that the outside margin of the ring *C* has always appeared to me to be more sharply defined on that part of the ellipse farther from the observer than on the side nearest. The case is the same for the outer border of the ring *A*, which appears sharper on its northern than on its southern side. In both cases, the northern portion of the ellipse is limited by the matter composing the surface of the rings on their flat and illuminated side; while for the southern portion it is seen a little edgeways, and this may account for the vagueness of its outlines on this side.

Soon after the beginning of my observations, in October, 1872, my attention was called to a singular appearance not heretofore noticed, as far as I am aware. Two small, dark, angular forms, *r*, Fig. 1, were seen near the summit of the principal division of the rings on the following side, and apparently projected upon the ring *B*. After an interval of three hours, no sensible change could be detected in the position of these forms; and on the following day they were seen occupying about the same position. This phenomenon could easily be explained by supposing there were some sort of protuberances on the external edge of the ring *C*, casting their shadow under the oblique rays of the sun, which occupied then a proper position to answer to this

FIG. 2.



hypothesis. But, some days later, another of these singular forms was observed 180° from the first, on the preceding side, at *s*. This at once overthrew the supposition that they were shadows cast by protuberances existing on the ring *C;* since in this case the shadows would have been projected opposite the sun on the ring *C*, and not on the ring *B*. Since that time, I have rarely observed the planet without seeing some of these singular appearances, either on one side or the other, but generally on both sides. The number of these dark forms is variable. One, two, three, four, and even five, have been seen at the same moment, and on the same side. Though these forms are variable, and appear and disappear, I have never been able to detect in one night any change of position which could be ascribed to the rotation of the rings.

The most plausible explanation of the phenomenon which I can conceive is, that the inner margin of the ring *B*, which forms the outer limit of the principal division, is irregular, jagged, and deeply indented, as shown at *A*, Fig. 2, which represents Saturn as it would appear to an observer placed above one of its poles.

As Bond speaks of the principal division of the rings as " not being perfectly elliptical," and as in one instance he has suspected that it " was narrower in some places," it is to be inferred that he had some faint glimpses of the phenomenon which I have observed, and which possibly may be more conspicuous now than twenty years ago.

But the fact that this phenomenon has not been observed earlier does not necessarily prove that it had no existence before; as it is well known, by those who have had experience with the telescope, that one may look for a long while at a celestial object, and miss perceiving what he will readily see when once he is told where to look, and what to look for. Seeing what is new and unsuspected is quite different from seeing what has been observed before.

Though no noticeable changes in the position of the dark angular forms could be observed in the course of two or three hours, it does not follow that the system of rings does not rotate upon an axis, as theory indicates; since the supposed indentations seen on the ansæ would be placed in the most unfavorable position for showing their motion, if they have any, because it would be accomplished almost in a line with the visual ray, either approaching or receding from the observer.

Next to this division, but much less conspicuous, and to be seen only on very good nights, is a narrow, grayish, and somewhat diffused line, called " the pencil line," shown at *b*, Fig. 1. I have never been able to trace this line all around the planet, as it diminishes very rapidly with the foreshortening, and is soon lost. Probably I have never traced it more than 30° or 40° on each side of the major axis of the rings. The pencil line has never appeared to me black and well defined, but rather grayish and diffused. Sometimes I have had the impression that it was irregular in width and in depth of tint.

These two lines are the only ones I have observed, which could, with a certain amount of probability, be said to be a separation of the rings; though they might just as well be depressions, or dark belts, especially the outer one. But the fact that they have been observed on both surfaces north and south, apparently corresponding in position, is in favor of their being real separations of the rings. Though I have repeatedly endeavored to see the planet through the principal division between *d* and *e*, Fig. 1, I have never seen the faintest traces of it; and I am not aware that others have been more successful.

If the principal division of the rings is, in fact, what it is said to be, — viz., a space free from matter, and entirely disconnecting the rings *B* and *C*, — I do not see why the planet has never been seen through it. If the planet could be seen through that space, the dark line forming the principal division would be invisible from *d* to *e*, as the bright light of the planet would shine through in its place, and be undistinguishable from that of the rings. It may be objected that the invisibility of the planet through the principal division is due to the thickness of the ring *C*; but, in this case, why should the black sky be seen, if the planet is invisible?

Besides the two dark gaps or divisions of which I have just spoken, the rings are subdivided by concentric zones or belts, which reflect light of different hues and intensity. Though only three of these belts are conspicuous, I have found by careful examination that there are six which I can always recognize whenever the illumination is good, and the image steady. These zones are represented on the diagram, Fig. 1, at *A*, *B*, *C*, *D*, *E*, *F*. On several occasions, I have had a pretty distinct impression of seeing the whole surface, from *C* to *E* inclusive, grooved, as it were, by numerous narrow concentric belts. These impressions may have been illusory, as they were almost instantaneous; but I have since learned by experience, that, after all, rapid impressions are not so much to be discarded, as, quite often, even more fugitive impressions have proved in the end to be real. A striking instance in my own experience may be worth recording. This Summer I made a study of the Horse-shoe Nebula in Sagittarius with my 6¼-inch refractor. During the course of my observations, I was much annoyed by what appeared to me as faint ghost-like reticulated shadows projected upon the nebula. I at first thought I had left the reticule of squares ruled on glass in the eye-piece; but having convinced myself that this was not so, and the same appearance again presenting itself, I wiped my eye, but with no better result. As I experienced the same thing on other nights, I paid no more attention to it, thinking the trouble was in my sight. Some time afterwards, while in Washington, I had an opportunity of studying the same nebula with the great twenty-six-inch refractor of the Naval Observatory. I was not a little surprised to see that the ghost-like reticule which I wanted so much to rub out of my eye while at home, was caused by dark channels in the nebula itself, which is divided on the preceding side by bright luminous patches, separated by dark intervals.

In order of brightness, the zones or belts composing the system of rings run as follows: *C*, *D*, *B*, *E*, *A*, *F*; *C* being by far the brightest, and *F* by far the darkest. The zones *A* and *B* have a bluish cast, or light slate-color; *C* is of a bright luminous white; *D* is slightly grayish; *E* is at little darker; while *F*, which is very dark, is tinged with bluish purple.

A is separated from *B* by the pencil line; *B* from *C* by the principal division; while the others do not show any separation whatever, and are only limited by the contrast of their different colors and shades, and seem to be in immediate contact. However, the different zones do not terminate abruptly where they come in contact, but seem somewhat blended into each other. This is especially the case between *E* and *F*. Though at that point the contrast between the two internal rings is very great, yet it is impossible to see any line of division, so much do they mingle at their point of contact.

On good nights, I have often observed on that part of the rings *A*, *B*, and *C*, seen on the ansæ, an unmistakable mottled or cloudy appearance such as is represented on Plate 1. This appearance was always more characteristic and better seen on the ring *C*, especially near its outer margin, close to the principal division. It would seem, as has been already remarked, that the ring *C* is on a higher level than that of the rest of the rings, and that the cloudy appearances observed there form by their accumulation some kind of protuberances of different heights and breadths. The bright spots resembling satellites, so often observed by Bond in 1848, when the plane of the rings was parallel with that of the ecliptic, were probably caused by the crests of some protuberances similar to those now seen on the ansæ. The form of the shadow thrown by the planet on the rings on Nov. 30, 1874, as shown at x, Fig. 1, seems also to agree with this hypothesis. The curious and deep indentation of the shadow at *x*, in that part where it is projected on the outer border of the ring *C*, is perfectly explained on the supposition that this part of the ring is on a higher level. The same shadow, as it appeared projected on the rings *B* and *A*, also clearly indicates that the plane of these zones is on a lower level.

In order to find the shape of the surface of the rings from the observation of the form of the shadow thrown by the planet, I have experimented on a miniature representation of Saturn, illuminated by a lamp occupying the position of the sun, while my eye occupied the position of the earth. By successive trials in altering the shape of the miniature rings, I have soon found what must be the form of the rings in order to give to the shadow the same appearance which had been observed on the planet; and the result agrees with the explanation already given.

From the form of the shadow as it has appeared at different times during the last four years, and from the experiment just mentioned, it seems pretty clear to me, that, from the inner margin of the dusky ring *F*, the thickness gradually increases until it reaches the extreme border of the ring *C*, where it gently decreases, as indicated by the rounding of the shadow at this point; after which it sinks perpendicularly down, until it comes even with the general level of the rings *B* and *A*. The slightly curved appearance of the shadow of the planet during the present year, with its concavity turned towards its globe, also supports this hypothesis.

Though, in general, the level of the ring *C* is always higher than that of the rest of the system, it does not seem, however, to be uniform and permanent, but varies, either by the rotation of the rings upon an axis, or by some local changes in the cloud-forms themselves; as in several instances I have observed quite rapid and striking changes taking place during the course of one evening in the indentation of the shadow shown at *x*, Fig. 1. Sometimes the indentation appeared to increase, indicating a higher level; and sometimes to decrease, indicating a lower level.

That the thickness of the rings is increasing from the interior margin of the dusky ring to the outer border of the bright ring *C*, seems to be corroborated by the phenomena which I have observed on the dusky ring, and of which I shall speak presently.

On all favorable occasions, I have made careful searches on the dusky ring for the divisions suspected by Bond; but I never had the faintest glimpses of them. The dusky ring appears to me to be continuous, though it is certainly not of the same thickness throughout. Whatever may be the material of which this ring is composed, it is quite rarefied; and it becomes more and more so as it approaches its inner margin. There, it seems to be composed of discrete particles, each of which reflects the light separately; and, by applying high powers to telescopes of large aperture, I have had the impression that the supposed particles were more widely separated by the increase of magnifying power. I do not pretend to have seen distinct and isolated particles in the dusky ring; but by instants my impressions have been so decided, that it seemed as if only a little more favorable conditions were required to enable me to see separate corpuscles of matter. The appearance was somewhat like fine particles of dust floating in a ray of light traversing a dark chamber.

The inner border of the dusky ring, notwithstanding its dark appearance, is sharply defined on the dark sky within the ansæ; but it loses this sharpness of outline in that part which is seen projected upon the disk of the planet. There it appears very diffused and ill defined.

The inner border of the dusky ring, as seen within the ansæ, forms a part of a perfect ellipse concentric with the other rings; but these graceful curves are remarkably and quite abruptly distorted where they enter upon the disk of the planet at *m* and *p*, Fig. 1. At these points, they are seen turning up rapidly, describing a short curve; after which they continue parallel with the curves of the other rings until they meet at *h*. If the ellipse described within the ansæ should cross the planet without any deflection, it would be seen along the dotted line, Fig. 1, and pass through *n;* while, on the contrary, it is seen above at *h*.

I was quite surprised, at first, by this singular phenomenon; but I at last satisfied myself with the following explanation: If we conceive the dusky ring to be made up either of vapors or of numerous small independent solid bodies, and, moreover, if we conceive the thickness of this ring as increasing from its interior margin to its outer limit, we shall have an easy explanation of the observed phenomena. When the matter composing this ring, whether solid or gaseous, is seen projected upon the disk of the planet brilliantly illuminated, it will be lost, and will individually disappear, absorbed by the irradiation of the bright light surrounding it, and it will remain visible only at that part where it forms a stratum thick enough to overpower the effect of irradiation.

The fact that the distortion of the inner margin of the dusky ring is not abrupt at *m* and *p*, where it enters upon the disk, but is gradual, seems to prove that the planet is less luminous on its border than elsewhere, providing the above explanation holds good; and this may be owing to the absorption caused by an atmosphere surrounding the planet.

Bond has represented the limb of the globe of Saturn as seen through the whole width of the dusky ring. In this he agrees with all previous observers. All the drawings of Saturn represent the limb of this planet as plainly and equally visible throughout the dusky ring, becoming invisible only where it enters under the internal margin of the ring *E*. In Bond's memoir, it is positively stated that Mr. Tuttle saw the limb of the planet through the whole width of the dusky ring. If these observations are correct, — as without doubt they are, — the solid particles, vapors or gases, composing this ring, must have undergone some changes of position since Bond's time; as by using the same instrument, and even one of almost double the aperture, I have not been able to confirm these observations.

During the last four years, I have never been able to see the limb of the planet Saturn under the dusky ring, beyond the middle of its width. As it enters under it at *m* and *p*, it remains quite distinct for a short distance: but, as it advances farther in, it diminishes gradually; and it entirely vanishes at about the middle, at *u* and *v*; as if the matter composing the dusky ring was more dense or thicker towards its outer border. This observation has been so carefully made, and so many times repeated, the phenomenon has been so distinctly seen, that there is not the least doubt in my mind as to its reality. Therefore it seems pretty certain that changes have lately taken place in the distribution of the matter composing the dusky ring.

As already shown, the substance composing the dusky ring does not seem to be uniformly distributed; but seems moreover to be agglomerated here and there into denser masses, which I have often recognized upon that part of the dusky ring crossing the planet between *u* and *v*. These supposed agglomerations appeared as dark masses, intercepting the light of the planet. This phenomenon could not be attributed to dark markings on the planet, seen through the dusky ring; since there are no markings so dark and so small on Saturn. Neither could they be produced by the dark bands sometimes surrounding the globe of Saturn, as some traces would have been detected on the edge of the dusky ring, since these bands are usually wider than the transparent part of the dusky ring.

Of the planet itself I have little to say. It has certainly a mottled or cloudy appearance, like Jupiter. The clouds of Saturn are more finely divided, like certain forms of the cirri clouds of our own atmosphere. The cloudy appearance of Saturn, of course, is not so easily seen as that of Jupiter. It always requires a good steady night to see it.

I have never seen the planet striped with a large number of parallel bands, such as some observers have described. Three or four form the extreme limit. Nor have I seen the bands so conspicuously marked, so regular, so distinct in outline, and so dark; the equatorial band being always by far the most conspicuous, while the others were barely perceptible. The equatorial belt has always appeared to me to be slightly tinged with a delicate carmine red, very much like the equatorial belt of Jupiter; only the pink color of the former is much fainter. In no instance could I compare the color of this band to "brick red," as it is commonly described.

Like the equatorial belt of Jupiter, that of Saturn is variable in width, and changes its form as well as its position. It is usually composed of two grayish irregular bands, forming its limits north and south, between which are seen flocculent pinkish cloud-forms.

The general color of the planet differs from that of the rings, in being of a slight warm brown in which there is a yellowish tinge. The contrast of color with the rings is better seen by the use of very high powers.

To conclude: my observations show, —

I. That the inner margin of the ring *B*, limiting the outer border of the principal division, has shown on the ansæ some singular dark angular forms; which may be attributed to an irregular and jagged conformation of the inner border of the ring *B*, either permanent or temporary.

II. That the surface of the rings *A*, *B* and *C*, has shown a mottled or cloudy appearance on the ansæ during the last four years.

III. That the thickness of the system of rings is increasing from the inner margin of the dusky ring to the outer border of the ring *C*, as proved by the form of the shadow of the planet thrown upon the rings.

IV. That the cloud-forms seen near the outer border of the ring *C* attain different heights, and change their relative position, either by the rotation of the rings upon an axis, or by some local cause; as indicated by the rapid changes in the indentation of the shadow of the planet.

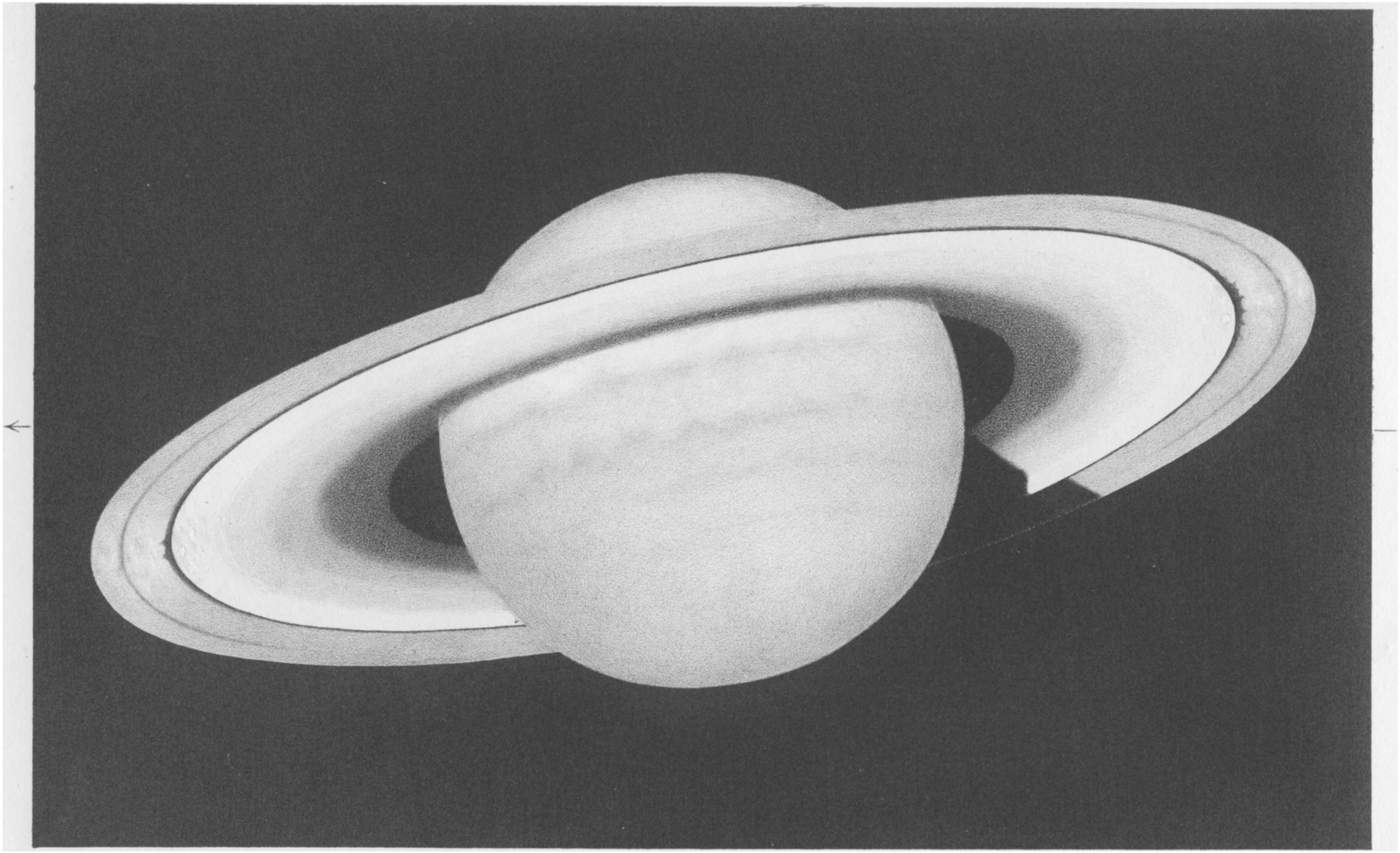
V. That the inner portion of the dusky ring disappears in the light of the planet at that part which is projected upon its disk.

VI. That the planet is less luminous near its limb than in the more central parts, the light diminishing gradually in approaching the border.

VII. That the dusky ring is not transparent throughout, contrary to all the observations made hitherto; and that it grows more dense as it recedes from the planet; so that, at about the middle of its width, the limb of the planet ceases entirely to be seen through it.

VIII. And, finally, that the matter composing the dusky ring is agglomerated here and there into small masses, which almost totally prevent the light of the planet from reaching the eye of the observer.

CAMBRIDGE, Dec. 1, 1875.



L. Trouvelot, del. J. Mayer Lith.

SATURN

Dec. 30th 1874